AD-A049 086 AEROSPACE CORP EL SEGUNDO CALIF IVAN A GETTING LABS F/G 4/1
VLF TRANSMISSION INDUCED SLOT ELECTRON PRECIPITATION.(U)
DEC 77 A L VAMPOLA F04701-77-C-0078
UNCLASSIFIED TR-0078(3960-05)-2 SAMSO-TR-77-217 NL

1 OF 1
AD
A049086

END
DATE
FILMED
3-78
DDC

ADA049086

AD No. ______
DDC FILE COPY

REPORT SAMSO-TR-77-217

12

VLF Transmission Induced Slot Electron Precipitation

A. L. VAMPOLA

Space Sciences Laboratory
The Ivan A. Getting Laboratories
The Aerospace Corporation
El Segundo, Calif. 90245

5 December 1977

Interim Report

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED

Prepared for
SPACE AND MISSILE SYSTEMS ORGANIZATION
AIR FORCE SYSTEMS COMMAND
Los Angeles Air Force Station
P.O. Box 92960, Worldway Postal Center
Los Angeles, Calif. 90009

This interim report was submitted by The Aerospace Corporation, El Segundo, CA 90245, under Contract No. F04701-77-C-0078 with the Space and Missile Systems Organization, Deputy for Advanced Space Programs, P.O. Box 92960, Worldway Postal Center, Los Angeles, CA 90009. It was reviewed and approved for The Aerospace Corporation by G. A. Paulikas, Director, Space Sciences Laboratory. Lieutenant Dara Batki, SAMSO/YCPT, was the project officer for Advanced Space Programs.

This report has been reviewed by tne Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

Dara Batki

Dara Batki, Lt, USAF
Project Officer

Robert W. Lindemuth

Robert W. Lindemuth, Lt Col, USAF
Chief, Technology Plans Division

FOR THE COMMANDER

Leonard E. Baltzell

Leonard E. Baltzell
Asst Deputy for Advanced Space Programs

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

19 REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER 18 SAMSO-TR-77-217

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle) 6 VLF TRANSMISSION INDUCED SLOT ELECTRON PRECIPITATION.

5. TYPE OF REPORT & PERIOD COVERED 9 Interim rept.,

6. PERFORMING ORG. REPORT NUMBER 14 TR-0078(3960-05)-2

7. AUTHOR(s) 10 Alfred L. Vampola

8. CONTRACT OR GRANT NUMBER(s) 15 F04701-77-C-0078, NAS5-22450

9. PERFORMING ORGANIZATION NAME AND ADDRESS

The Aerospace Corporation
El Segundo, Calif. 90245

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 12 19p.

11. CONTROLLING OFFICE NAME AND ADDRESS

Space and Missile Systems Organization
Air Force Systems Command
Los Angeles, Calif. 90009

12. REPORT DATE 11 5 Dec[redacted]77

13. NUMBER OF PAGES 14

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report) Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Magnetospheric Electrons
Wave-Particle Interactions
VLF Effects

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Analysis of electron observations in the drift and bounce loss cones of the slot region of the magnetosphere indicates that the predominant mode in which electrons in the 100 to 400 keV energy range arrive in the drift loss cone is via discrete events. These events are usually traceable back to the vicinity of a high-power-level VLF transmitter. No gradual buildup of electron flux, proceeding eastward from the South Atlantic Anomaly, is observed. Estimates of the loss rate due to the discrete events show that this process can result in a depletion of 50% per day of the electron flux in the slot region. The wave-particle

DD FORM 1473 (FACSIMILE)

409 944

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

mt

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

19. KEY WORDS (Continued)

LAMBDA APPROXIMATELY deg deg

20. ABSTRACT (Continued)

interaction must occur relatively low on the field line ($\lambda \approx 30^\circ$ to 50°) because of the relationship of particle energies and wave frequencies involved. Additional scattering of the particles near the equator, either by power-line harmonic emissions or naturally occurring ELF hiss, is required to transport the particles to the lower interaction region.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

PREFACE

The author would like to express his gratitude to B. Edgar, H. Koons, T. Potemra, and others who provided assistance in the difficult task of locating and identifying VLF stations. A portion of this research was supported by Contract NAS5-22450.

CONTENTS

FIGURES

Preceding Page BLANK - NOT FILMED

OBSERVATIONS

Recent disclosure of precipitation of energetic electrons in the inner electron zone ($L \approx 1.5$ to 2) by a VLF transmitter located in the region of Gorkiy, USSR (Vampola and Kuck, 1977; Edgar et al., 1977), coupled with observations that suggest power-line emissions might be effective in scattering electrons in the outer zone (Helliwell et al., 1975) and in the slot region of the magnetosphere (Bullough et al., 1976), naturally lead to speculation about the role of VLF transmissions in causing the slot-region and outer zone electron precipitation. A major objection to the hypothesis that VLF transmissions might be effective in producing the electron slot and contributing to the "drizzle" of outer zone electrons into the atmosphere has been the resonance condition in the equatorial region: VLF waves from ground-based transmitters (10 to 25 kHz) would resonate only with sub-keV to a few keV electrons at the equator; away from the equator, the resonance conditions change rapidly and a large wave intensity is required to produce significant pitch angle scattering. However, a recent observation of emission stimulation and/or wave entrainment well away from the equator (Inan et al., 1977) has removed this objection. Essentially simultaneously with this development comes the following experimental evidence that ground-based VLF transmissions do, in fact, precipitate substantial quantities of energetic electrons in the slot region.

Figure 1 is a plot of data from various electron channels on the OV1-19 (1969-25C) spacecraft (Vampola, 1971). The scatter in the data points in the peaks is due to pitch-angle sampling. The pronounced "banding" of fluxes above background in Figure 1c is due to sampling rates in near-synchronism with the spin rate of the satellite. All of the data were obtained in the drift loss-cone; that is, although these particles have both mirror points at altitudes above 100 km at the longitude where they were observed, their mirror-point trajectories will be below 100 km at some other longitude. Drift periods for these particles vary from less than an hour to several hours. All three of the data sets, 1a, b, and c, exhibit the same phenomenon — an L-dependent precipitation spike in the region $2 \le L \le 3.5$. (L-dependent refers to the behavior as a function of energy: lower energy electrons are precipitated at higher L locations). Figure 1b also exhibits a peak of the type discussed by Vampola and Kuck (1977). In that study, only the region $1.5 \le L \le 2$ was

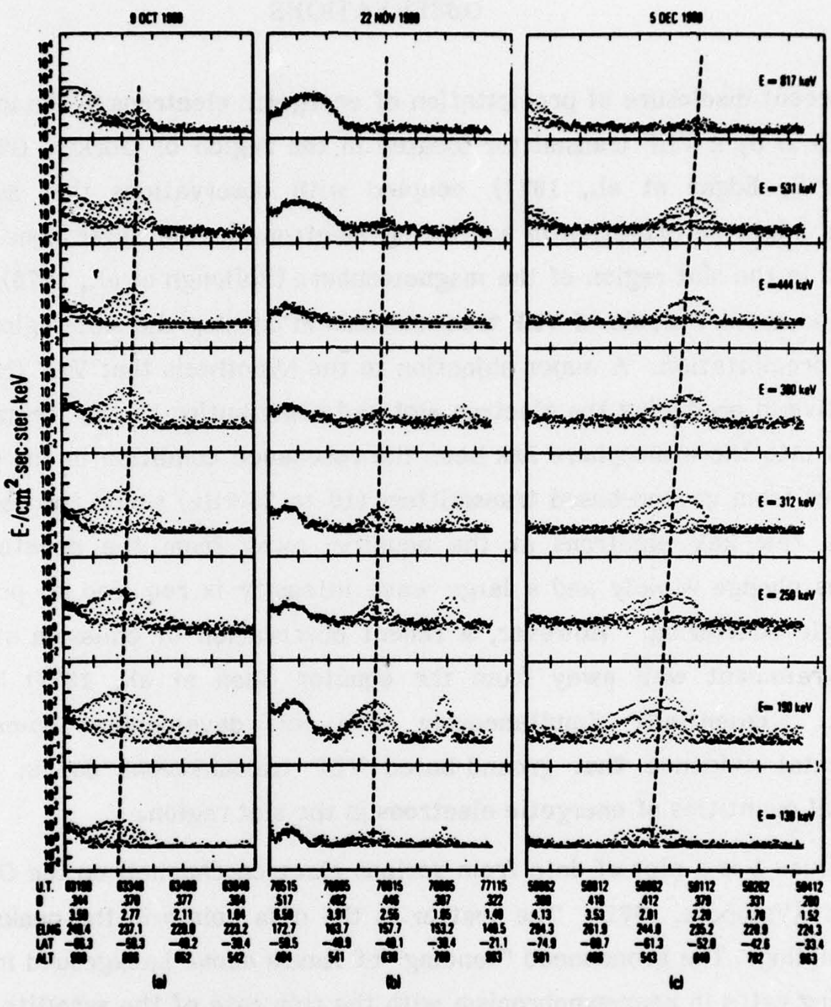

Figure 1. **Flux Versus Time Plots of OV1-19 Electron Data Showing L-Dependent Precipitation Events in the Drift Loss Cone. The slot events of 1(a) and 1(b) (marked with a dashed line) map back to east longitudes of 50° and 57°, respectively. The event at L = 1.7 in 1(b) maps back to 55°EL. The event in 1(c) cannot be traced back past 190°EL because of the magnetospheric configuration at that point. The fluxes at the extreme left in each figure are normal outer zone fluxes. B is the magnetic field in gauss and L is McIlwain's parameter.**

investigated, since an earlier data set which initiated the study (from the OV1-14 satellite) contained drift loss cone measurements only in that interval. As can be seen, these precipitation events involve a very significant flux, all of which will be lost into the atmosphere *during the immediate drift period*. (A very small fraction may remain as degraded fluxes due to large-angle scattering which may occur in the residual atmosphere higher up.) Such precipitation spikes were observed on about 95% of the passes through the drift loss-cone (approximately 200 passes in the data set examined). In some of these events, only one or two energy channels showed significant fluxes.

The location of the last interaction of these particle distributions with the atmosphere can be determined through an analysis of the size of the observed cut-off in the pitch-angle distribution in comparison with the expected variation in the size of the atmospheric loss cone as a function of longitude around the drift shell. See Luhmann and Vampola (1977) for details of this mapping procedure. Due to the finite aperture effects of mechanical collimators and the finite rise and decay times of countrate meters, one must fit the observed distribution to a calculated response function in order to determine the loss cone angle accurately. The result for the data of Fig. 1a is a cut-off at 66 ± 1^{o}, corresponding to an equatorial pitch-angle of $10.49 \pm .08^{o}$. In turn, this equatorial loss-cone angle maps back to a longitude of 50.5 ± 2^{o} at $L = 2.77$. That is, we assume that the locally observed cut-off, when it is substantially larger than the loss-cone allowed by the local magnetic and atmospheric geometry (56^{o} for this location) was determined by interaction with the atmosphere at some past point in its drift and has remained unchanged since.

A similar analysis of the pitch-angle distributions of Fig. 1b resulted in an east longitude of last interaction with the atmosphere of 57.5 ± 0.8^{o} for the structure at $L = 2.55$ and an east longitude of 55 ± 2.3^{o} for the structure at $L = 1.72$. The final example, Figure 1c, cannot be mapped back to its point of origin. The local cutoff angle obtained for the data is 64^{o}. This translates to an equatorial loss-cone angle of $11.76 \pm .05^{o}$. The data were obtained at about 240^{o} EL. If one maps back along the $L = 2.48$ drift shell, one finds that at about 190^{o} EL the local atmospheric loss-cone subtends about 11.70^{o} at the equator. These particles must have last interacted with the atmosphere at that location. However, this is also the largest loss-cone angle on the drift shell between about 67° EL and the position of the satellite. Hence, the electrons were almost certainly lowered in mirror point somewhere between 67° EL and 190° EL. The pitch-angle distribution was then modified by interaction with the atmosphere at the 190° location. Note that in all of these calculations, it is not possible by using a single observation to determine how broad a region in longitude the wave-particle interaction covers. (Given very precise pitch-angle distribution data and a foreknowledge of the strength of the interaction as a function of east longitude, in theory it is possible to obtain this information from a single pitch-angle distribution. In practice, one cannot do it with this data set with the present state of our knowledge of the interaction.)

In the search for precipitation events, four were observed at times when the satellite was in the local bounce loss cone: i.e., a particle mirroring at the position of the satellite would mirror below 100 km at the conjugate point. Hence, all electrons observed were going to be lost within a bounce period. For three of these events, the satellite was between 40° and 44°EL; for the other, it was at 288°EL. These correspond approximately to the VLF communication stations UMS and NAA.

Figure 2 is a plot of the average flux of electrons in the drift and bounce loss cones as a function of east longitude in 3° bins with the following conditions: $139 \le E_e \le 312$ keV; $1.5 \le L \le 4.0$; $C_p < 16$ cps, where C_p is the countrate in the energetic proton/cosmic ray background monitor. The reason for this last condition is that the rejection efficiency for cosmic rays and other penetrating particles in the electron detectors is only 95%-97%. Hence, this threshold insured that background would be negligible in the final result. Note that the data have been averaged over all latitudes corresponding to the $1.5 \le L \le 4.0$ criterion. Also, note that the latitudinal averaging was done over geographic latitude, not over field line orientation. The data set included high altitude data as well as the low altitude data of the type used for the drift loss cone events of Figure 1. Since no distinction was made between drift and bounce loss cone data in assembling statistics for Figure 2, most of the data samples were obtained in the bounce loss cone, since at any given point in space, the bounce loss cone subtends a much larger angle than the drift loss cone. The minimum number of data samples in any 3° bin was 415, with 717 being the average number.

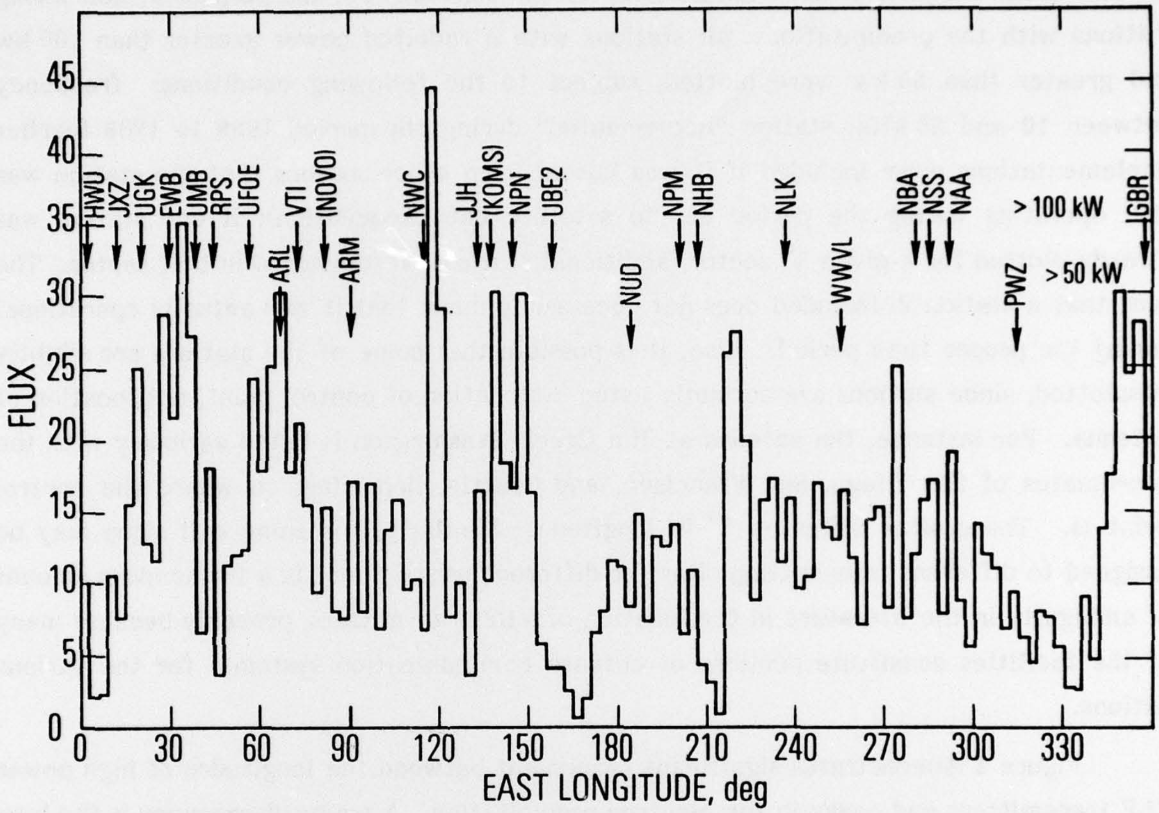

Figure 2. Average Precipitated Flux, $139 \leq E_e \leq 312$ keV, in the Region $1.5 \leq L \leq 4$ Plotted as a Function of East Longitude for the Time Period 1969. Also plotted are the locations of VLF transmitters with authorized power levels > 50 kw and >100 kw.

Figure 2 also indicates the location of various VLF stations as listed in the "International Frequency List" (8th Edition, I.T.U., Geneva). For the purpose of comparing stations with the precipitations, all stations with a radiated power greater than 100 kw and greater than 50 kw were plotted, subject to the following conditions: frequency between 10 and 25 kHz; station "implemented" during the period 1959 to 1968 (earlier implementations were included if it was known from other sources that the station was still operating during the period of the satellite data acquisition); if one station was already plotted for a given 3° sector, additional stations were ignored in that sector. The fact that a station is included does not necessarily mean that it was actually operational during the proper time period. Also, it is possible that some of the stations are slightly misplotted, since stations are normally listed by location of control point, not location of antenna. For instance, the antenna at Jim Creek, Washington is listed variously with the coordinates of San Diego, San Francisco, and Seattle, depending on where the control point is. These sites differ by 5° in longitude. Similarly, the same call signs may be assigned to different transmitting sites for different uses. There is a tremendous amount of ambiguity in the literature in the location of VLF transmitters, probably because many of the facilities constitute portions of defense communication systems for the various nations.

Figure 2 demonstrates significant agreement between the longitudes of high power VLF transmitters and peaks in the electron precipitation. A major discrepancy is the lack of a peak associated with UBE2 at 158°. Satellite measurements of VLF signals have shown a strong "antipodal" effect, whereby significant enhancements of signals from NAA and NPG are seen above the antipode. In fact, one observation of an enhancement in the northern hemisphere was explained as a whistler-mode signal excited in the southern hemisphere by a 20 dB antipodal enhancement (Heyborne, 1966). The large uncorrelated precipitation peak at about 220°EL may be such an antipodal effect from the Soviet transmitters located near 40°. Another large peak, at about 275°EL, seems to correlate with a peak at 97°EL — possibly due to NBA and its antipode. NBA does not correlate precisely with any peak; yet, it is one of the most powerful transmitters in the list. Other antipodal effects may also result in minor precipitation peaks. There is one other large peak, at about 350°EL, which does not seem to correlate with stations selected according to the criteria outlined above. A station at Payneswardd (349°EL) was authorized as of 1975. If it also existed during the 1969 time period, it may be responsible for this last peak.

It is significant that the data of Figure 2 do not show a gradual buildup in flux as the electrons drift eastward from the region of the South Atlantic anomaly. If precipitation were uniform in longitude, one would expect to see a monotonically increasing flux in the drift loss cone until the region of the South Atlantic anomaly is approached. The flux in the bounce loss cone should be approximately constant until the region of the anomaly is approached, at which point flux in the drift loss cone would enter the local bounce loss cone. Thus, for natural sources of pitch-angle scattering which are uniformly distributed in longitude, Figure 2 should have a minimum at the anomaly, a gradual buildup eastward of it, and finally a sharp increase as the anomaly is approached from the west. Note that in the region of the western Pacific, where there are relatively few transmitters, there is also a minimum in the precipitating flux. In fact, in one 3° bin, it is at the background level of the instrumentation.

DISCUSSIONS

The data of Figure 1 show very substantial fluxes of electrons in the drift loss cone. Typically, fluxes of the order of 1×10^3 e^-/cm^2-sec-ster-kev between 200 and 400 keV are observed in these precipitation events. Intensities decrease at energies above and below those energies. Undoubtedly, the total flux precipitated must depend on the trapped flux intensity which, unfortunately, was not measured above 5500 km in this experiment. However, a reasonable estimate of the significance of this precipitation mechanism can be made by assuming the loss cone is filled once per drift period. The technique will underestimate the loss, on one hand, since the interactions are taking place over a finite longitudinal region and the bounce loss cone may be filled continuously over that region; on the other hand, the interaction probably does not produce complete isotropy in the interaction region. These two errors produce opposite effects and should partially cancel. These assumptions also imply that rapid reconfiguration (within one drift period) of the flux distribution near the equator occurs through some other interaction (possibly either power line harmonics or magnetospheric hiss, if they are distinct). Such a calculation indicates a loss rate of 2% to 4% per drift period, resulting in a loss rate for the total flux on a field line of about 50% per day, which is sufficient to account for the slot in that region. The calculation assumes a single location in longitude is effective. The data of Figure 2 indicate that probably most high powered VLF transmitters are effective in producing such precipitation. If so, the actual loss rate would depend on the rate at which electrons high on the field line are transported to the lower altitudes where the interaction with the artificially generated VLF waves takes place. If the equatorial interaction is weak compared to the lower-altitude interaction, one would expect a pronounced "shoulder" in the equatorial pitch-angle distribution corresponding to the upper limit of the VLF interaction region. The equatorial distributions have been observed to have such a shape at energies comparable to those under discussion here. Lyons et al. (1972) published OGO-5 data of this type and utilized a combination of cyclotron and Landau resonances to explain enhanced scattering all along the field line.

PrecedING Page BLANK - NOT FILMed

The analysis in this present work indicates that electrons in the slot region are scattered in discrete events. The analysis of Lyons et al., which results in continuous diffusion, is not consistent with the present data. The analysis of scattering location used in Figure 1 and tracing methods such as were outlined in the discussion of Figure 1 result in a picture of precipitation occurring at a small number of discrete locations in geographic longitude. The L-dependence of the peak in precipitation as a function of energy also requires resonance with a monochromatic wave.

The existence of high-powered VLF transmitters predates World War II. If such transmitters are the primary cause of the slot, and it appears that they may be, they have had a profound effect on the particle population in the inner zone (which, of course, would then be the inner region of a single zone extending out to the present outer zone boundary). In the absence of the rapid precipitation in the slot region, electrons would diffuse radially inward, being energized. Measurements of the lifetime of electrons in the inner zone produce values of the order of 400 days. Hence, equilibrium could be established in the order of three years. Using observed diffusion to and through the slot region during exceptionally magnetically disturbed times as a guide, the probable result of removal of all VLF transmitters (if, for instance, satellites were used for all communications and navigation purposes) would be a very intense belt of very relativistic (>5 MeV) electrons. Because of their high rigidity, the primary energy loss would probably be synchrotron radiation. It is not known whether any data exists, pre-WWII, which might address this speculative situation. Such an environment would be much more hostile to spacecraft than the post-Starfish environment. It might be necessary to continue to radiate VLF waves at high intensity just to prevent such a hostile environment.

If high powered VLF transmitters routinely precipitate electrons, and it appears that they do, they may be responsible for the discrepancy in electron density in the ionosphere as measured by various investigators (see Morse and Rice, 1976). Measurements by rocket-borne instruments launched in the USSR and from Wallops Island, Va. show significantly higher electron densities than measurements made from White Sands, NM. There are high powered VLF transmitters near the longitude of the USSR and Wallops Island launch sites, but not of the White Sands site.

It is also possible that the energy input into the upper atmosphere in the vicinity of such transmitters has a measureable effect on the weather. Bremsstrahlung produced at 80-100 km heights could penetrate to the lower atmosphere and produce ions which then act as nucleation centers for water droplets. Such bremsstrahlung would also act as a background in rocket-borne sensors used to measure galactic x-ray intensities. Hence, White Sands could be expected to be a better launch site than others which are in the vicinity of high power VLF transmitters (Luhmann and Blake, 1977). Presumably a number of other anomalies in atmospheric, ionospheric, and magnetospheric research results are also caused by the localized electron precipitation induced by these transmitters.

These and other questions, such as the details of the interaction between the waves and the particles as a function of frequency, pitch-angle, radiated power, electron energy, etc., are beyond the scope of a letter and are being addressed in work now in progress. The discovery of this strong effect of man-made waves on the electron population in the magnetosphere reinforces the possibility of intentionally modifying that particle population. It also provides direction for further research in a broad area of magnetospheric/ionospheric interactions.

REFERENCES

Bullough, K., A. R.L. Tatnall and M. Denby, Man-made ELF/VLF emissions and the radiation belts, Nature, 260, 401. 1976.

Edgar, B. C., H. C. Koons, and A. L. Vampola, Induced precipitation of inner zone electrons: 2. Resonant Calculations, EOS Transactions AGU, 58, 483, 1977.

Helliwell, R. A., J. P. Katsufrakis, T. F. Bell, and R. Raghuram, VLF line radiation in the earth's magnetosphere and its association with power system radiation, J. Geophys. Res., 80, 4249, 1975.

Heyborne, R. L., Observations of Whistler-mode Signals in the OGO Satellites from VLF Ground Station Transmitters, Stanford Technical Report SEL-66-094, Stanford University, California (1966).

Inan, U. S., T. F. Bell, D. L. Carpenter, and R. R. Anderson, Explorer 45 and Imp 6 Observations in the Magnetosphere of Injected Waves from the Siple Station VLF Transmitter, J. Geophys. Res. 82, 1177, 1977.

Luhmann, J. G. and J. B. Blake, Rocket Altitude Atmospheric X-rays from Magnetospheric Electrons at Low and Middle Latitudes, JATP, 1977 (In Press).

Luhmann, J. G., and A. L. Vampola, Effects of localized sources on quiet-time plasmasphere electron precipitation, J. Geophys. Res., 82, 2671, 1977.

Lyons, L. R., R. M. Thorne, and C. F. Kennel, Pitch-angle diffusion of radiation belt electrons within the plasmasphere, J. Geophys. Res., 77, 3455, 1972.

Morse, F. A., and C. J. Rice, Mid-latitude E region: An examination of the existance of a corpuscular source, J. Geophys. Res., 81, 2795, 1976.

Vampola, A. L., Access of solar electrons to closed field lines, J. Geophys. Res., 76, 36, 1971.

Vampola, A. L. and G. A. Kuck, Induced precipitation of inner zone electrons: 1. Observations, (Submitted to the Journal of Geophsyical Research, 1977); EOS Transactions American Geophysical Union, 58, 483, 1977.

THE IVAN A. GETTING LABORATORIES

The Laboratory Operations of The Aerospace Corporation is conducting experimental and theoretical investigations necessary for the evaluation and application of scientific advances to new military concepts and systems. Versatility and flexibility have been developed to a high degree by the laboratory personnel in dealing with the many problems encountered in the nation's rapidly developing space and missile systems. Expertise in the latest scientific developments is vital to the accomplishment of tasks related to these problems. The laboratories that contribute to this research are:

Aerophysics Laboratory: Launch and reentry aerodynamics, heat transfer, reentry physics, chemical kinetics, structural mechanics, flight dynamics, atmospheric pollution, and high-power gas lasers.

Chemistry and Physics Laboratory: Atmospheric reactions and atmospheric optics, chemical reactions in polluted atmospheres, chemical reactions of excited species in rocket plumes, chemical thermodynamics, plasma and laser-induced reactions, laser chemistry, propulsion chemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, photosensitive materials and sensors, high precision laser ranging, and the application of physics and chemistry to problems of law enforcement and biomedicine.

Electronics Research Laboratory: Electromagnetic theory, devices, and propagation phenomena, including plasma electromagnetics; quantum electronics, lasers, and electro-optics; communication sciences, applied electronics, semiconducting, superconducting, and crystal device physics, optical and acoustical imaging; atmospheric pollution; millimeter wave and far-infrared technology.

Materials Sciences Laboratory: Development of new materials; metal matrix composites and new forms of carbon; test and evaluation of graphite and ceramics in reentry; spacecraft materials and electronic components in nuclear weapons environment; application of fracture mechanics to stress corrosion and fatigue-induced fractures in structural metals.

Space Sciences Laboratory: Atmospheric and ionospheric physics, radiation from the atmosphere, density and composition of the atmosphere, aurorae and airglow; magnetospheric physics, cosmic rays, generation and propagation of plasma waves in the magnetosphere; solar physics, studies of solar magnetic fields; space astronomy, x-ray astronomy; the effects of nuclear explosions, magnetic storms, and solar activity on the earth's atmosphere, ionosphere, and magnetosphere; the effects of optical, electromagnetic, and particulate radiations in space on space systems.

THE AEROSPACE CORPORATION
El Segundo, California